

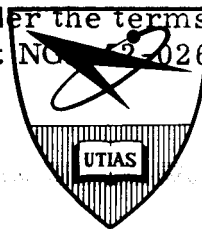
SEMI-ANNUAL REPORT
on
OPERATION OF AN MHD POWER GENERATOR
for the period

December 1, 1966 to June 1, 1967

prepared for

Spacecraft Technology Division
Lewis Research Center
National Aeronautics and Space Administration
Cleveland, Ohio

under the terms of
Grant NO. 52-026-012



submitted by

Stanley J. Townsend
Institute for Aerospace Studies
University of Toronto

August 11, 1967

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SUMMARY

Vacuum testing of the argon supply line and the heater are under way prior to taking the heater up to 2000°K for the first time. These preliminary heating tests with no flow are planned for the first week in September.

The electromagnet has had preliminary tests done on the coils in order to measure the rise time of the current surges when the unit is turned on. These tests are planned for the last week in August. Only a small amount of water piping remains to be done.

The seeding mechanism is nearing completion and should be ready for preliminary tests in a hot flow in mid-September. Schlieren equipment has been borrowed from another group in the laboratory and will take about one week to set up to measure uniform diffusion of the seed.

The first section of channel has been constructed and awaits thermal testing in early September. A second section is being fitted out with the conductivity probes which have been built. Preliminary tests of boundary layer growth at $M = 0.5$ bear out earlier calculations. These indicate a boundary layer thickness of about 1 cm at the end of the channel at $M = 0.8$.

1. INTRODUCTION

This report is the third semi-annual progress report written under Grant NGR 52-026-012. It covers the period from December 1, 1966 to June 1, 1967. This grant is supervised under the guidance of Mr. N. John Stevens, Spacecraft Technology Division, Lewis Research Center, National Aeronautics and Space Administration. The grant is for the investigation of the operation of a large, inert gas, magnetogasdynamic power generator with specific emphasis on low-pressure operation.

This research is co-sponsored with NASA. Equipment costs for the facility are being met by research grants from the Defence Research Board and from the National Research Council of Canada.

Scientific Personnel

Stanley J. Townsend, Assistant Professor
B. Grace, Research Assistant *
C. Hersom, Research Assistant *
C. Yeh, Research Assistant *
Marion Ferguson, Summer Student
J. Manning, Summer Student
W. Roger, Summer Student
A. Rosen, Summer Student

* M.A.Sc. students

2. INERT GAS GRAPHITE HEATER - C. Hersom, J. Manning and A. Rosen

Since the previous report, all the lampblack thermal insulation has been removed and has been replaced by two inches of graphite felt. It is expected that the temperature beyond the felt will be low enough that Carborundum Fibrefrax insulating blanket can be used to complete the eight inches of insulation, resulting in a considerable cost saving over an all-felt shield. This should allow operation up to about 2500°K.

The use of lampblack resulted in a mildly dirty laboratory which has had to be cleaned repeatedly. The pebble bed has been run cold for many hours being blown down with air to clean all the lampblack out. This problem now appears to be under control.

In order to avoid high oxidation rates of the graphite components, the entire system is being made leak tight down to the sub-Torr range. Vacuum sealing a large engineering facility is time consuming but we expect by the end of August to have this completed. Liberal use is being made of other groups' equipment and know how on this particular problem. An emergency,

recirculation cooling system capable of dissipating 145 kW (500,000 BTO/hr) has been designed and will be ready for testing at the end of August. This will allow us to cool the heater safely in the event of an unexpected break in water or power services. The design consists of an independent gasoline engine driving a water recirculating pump and an alternator. The alternator drives the fans on the three cooling units.

The argon supply and regulator system is completed with the high pressure manifold, high and low pressure regulators and mass flow meter in place. Mass flows sufficient to give 13 psia static pressures in the channel are possible. Figure 2.1 shows a schematic of the control scheme.

3. SEEDING MECHANISM - C. Yeh and W. Roger

After constructing the seeding mechanism, the rest of the seed injection system was designed. It has been decided to use sodium-potassium liquid metal (NaK) as the seeding material. NaK is chosen for its ease in handling at room temperature and its low boiling point when comparing with the other tentative materials. A review of the literature on physical and chemical properties of NaK was made. The safety aspect in handling this substance was also taken into consideration.

The basic idea is to vaporize the liquid NaK first before it is injected into the inert gas heater where vigorous mixing with argon gas occurs. A boiler, expected to cover the overall operating range, has been designed (see Fig. 3.1). Essentially it consists of a 40 cm (16 in.) diameter stainless steel boiler contained within an 80 cm (24 in.) diameter carbon steel shell. The entire volume of the stainless steel heater is filled with graphite pebbles 1.9 cm (0.75 in.) diameter, 2.5 cm (1 in.) long. This forms the pebble-bed heat exchanger which allows vaporization of potassium in a smooth flow. Furthermore the large thermal capacity will maintain the temperature fairly constant during runs. Uniform heating (to about 1100°K (1520°F)) around the pipe wall is achieved by electrical heating using carbon cloth as the heating element. Fiberfrax blanket is used in between pipe walls for thermal insulation. Liquid NaK enters the boiler at the bottom. The alkali vapour leaves at the top through a choked orifice which, for given pressure conditions, will maintain the mass flow rate of the seeding material constant. After much trial and error with free boiling in the injection tube this method has been suggested by the Institute für Plasma Physik in a private communication. The orifice diameter can be varied in between runs thus accommodating different argon flow rates and also different mole percentages of seeding. The space in between the pipes is evacuated because carbon cloth can only operate up to 590°K (600°F) in air, whereas it can operate satisfactorily up to 3020°K (5000°F) in vacuum. A 10 kW motor-generator set is used to supply the power to the heater.

The overall seed injection system is shown in Fig. 3.2. Nitrogen is used both as a cover gas in the NaK container and for purging the system piping and chambers. This precaution is taken because NaK will react violently with air.

Alkali metal vapour is injected into the exit plenum chamber through a 3.8 cm (1 1/2 in.) O.D. 2.5 cm (1 in.) I.D. graphite pipe. The pipe projects vertically into the plenum through a 5 cm (2 in.) diameter hole at the top of the graphite core (see Fig. 3.3). The inert gas plus the seeding material is mixed here and flows down through the MHD channel. To prevent condensation of NaK vapour in the injection pipe, the stainless steel pipe leaving from the boiler to the graphite injection pipe is heated to 1100°K (1520°F) by the same method as for the boiler. Breakage of the graphite pipe due to stresses set up by the condensed alkali metal vapour is prevented by lining the inner wall of the graphite pipe with molybdenum tubing. The graphite pipe is retained as a protective sleeve because carbon fumes might carburize the molybdenum tubing. Allowance for varying the projecting length of the injection pipe is included in the design so that optimum mixing with the argon flow can be achieved. Thermal expansion of the injection pipe is taken into consideration thus maintaining the exit end fixed relative to the plenum.

Smoke tests are planned to check the mixing pattern, followed by Schlieren tests to observe any density gradients in seed across the channel.

A single control panel for the handling of NaK and all seeding functions is being installed. Construction of the entire seeding facility is expected to be complete by the end of August.

4. POWER GENERATION CHANNEL - C. Hersom

The first channel has been assembled in six sections each 30 cm. in length with channel dimensions of 5 x 10 cm. The channels are fabricated from 1.3 cm (1/2 in.) alumina plates corner-notched for ease of assembly. The channel cooling will be copper tubing soldered onto the stainless duct.

Cold flows with the channel and a traversing total pressure probe and static wall tap mounted in one section have yielded data on the boundary layer. For $M = 0.5$ the boundary layer thickness increases as the square root of the distance downstream from the nozzle and at the end of the channel (about 1.8 m), the thickness was about 1.4 cm.

In one section of the channel installation of the first electrode configuration is completed. The electrodes are 1.5 mm tungsten rods

mounted parallel to the magnetic field axis and about 1.2 cm from the side walls with spacing of 2.5 cm down the length of the channel. Each section contains 10 pairs of electrodes.

The electrode design allows freestream operation as the electrodes are outside the boundary layer (Fig. 4.1). They are designed to be easily interchangeable and replaceable. The top and bottom plates are bored to fit a coil of wire which at the hot end loads onto a graphite disc 10 mm (3/8 in.) diameter and 3 mm (1/8 in.) thick which in turn is drilled half way through to accept the tungsten electrode (Fig. 4.2). The cold end of the wire coil is passed through a hollow ceramic-to-metal feedthrough in the stainless steel wall. The purpose of the coil is to allow thermal expansion of the electrode and to remove the current from the channel.

Since the coil must stand high temperatures at the one end, molybdenum wire will be used although a nickel alloy is presently being used for low temperature work. The electrical contact between coil and the graphite disc will improve as the electrode expands and pressure is exerted at the coil-disc junction. High temperature brazing of the coil to the graphite disc is possible and will be tried.

5. ELECTROMAGNET FACILITY - B. Grace

The pole pieces and coils were assembled on the magnet body and low voltage tests were performed on the coils to determine the current rise time and the magnitude of the back emf on breaking the circuit. It was decided to use a Westinghouse semiconductor diode as a "crowbar" to limit the back emf; the current rise time is more than one second and thus poses no problems. Final connections to the power supply are almost completed (see Fig. 5.1).

Manifolds for the water cooling system have been constructed and are now being installed along with associated plumbing. The magnet coils are being wrapped in fibreglass for extra protection against abrasion. Full scale testing of the magnet will begin shortly.

6. PROBE DIAGNOSTICS - B. Grace and Marion Ferguson

It has been decided to begin the study of the plasma in the MHD channel by determining voltage gradients in the plasma by means of a grid of four partially insulated internally cooled sensing electrodes. A device has been designed and constructed which should permit cooling the probes to a

temperature at which thermionic emission does not seriously affect voltage measurements. This uses an organic coolant similar to that in some experimental nuclear reactors. These probes will initially float at plasma potential and draw negligible current. They can also be used to investigate the current drawn with an applied voltage. Two sets of probes have already been constructed and will be installed in one channel section.

A set of ten isolating difference amplifiers and a variable time-base switching circuit have been designed and are currently under construction. This circuitry permits sampling electrode voltage drops for forty to fifty electrode pairs and also the voltage gradients between the sensing electrodes described above without affecting the conditions in the plasma. A power stage in the output drives a twenty-channel Honeywell Visicorder directly.

7. SPECTROSCOPIC DIAGNOSTICS - S. Townsend, C. Hersom and A. Rosen

Design work is proceeding on sapphire windows for the side walls (top and bottom also) and on a traversing rig for investigating cross channel variations. Delivery has been taken of a 0.5 meter Spex spectrometer. Our interest lies primarily in radiation losses from the excited seed atoms near the electrodes and other boundaries.

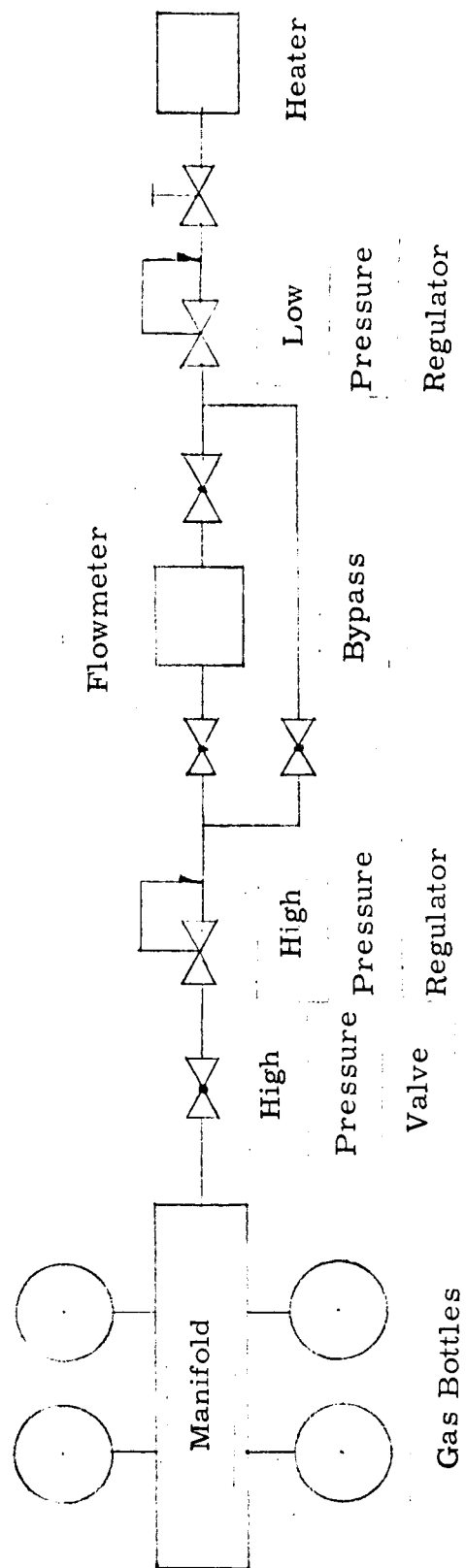


FIG. 2.1 GAS CONTROL AND REGULATION

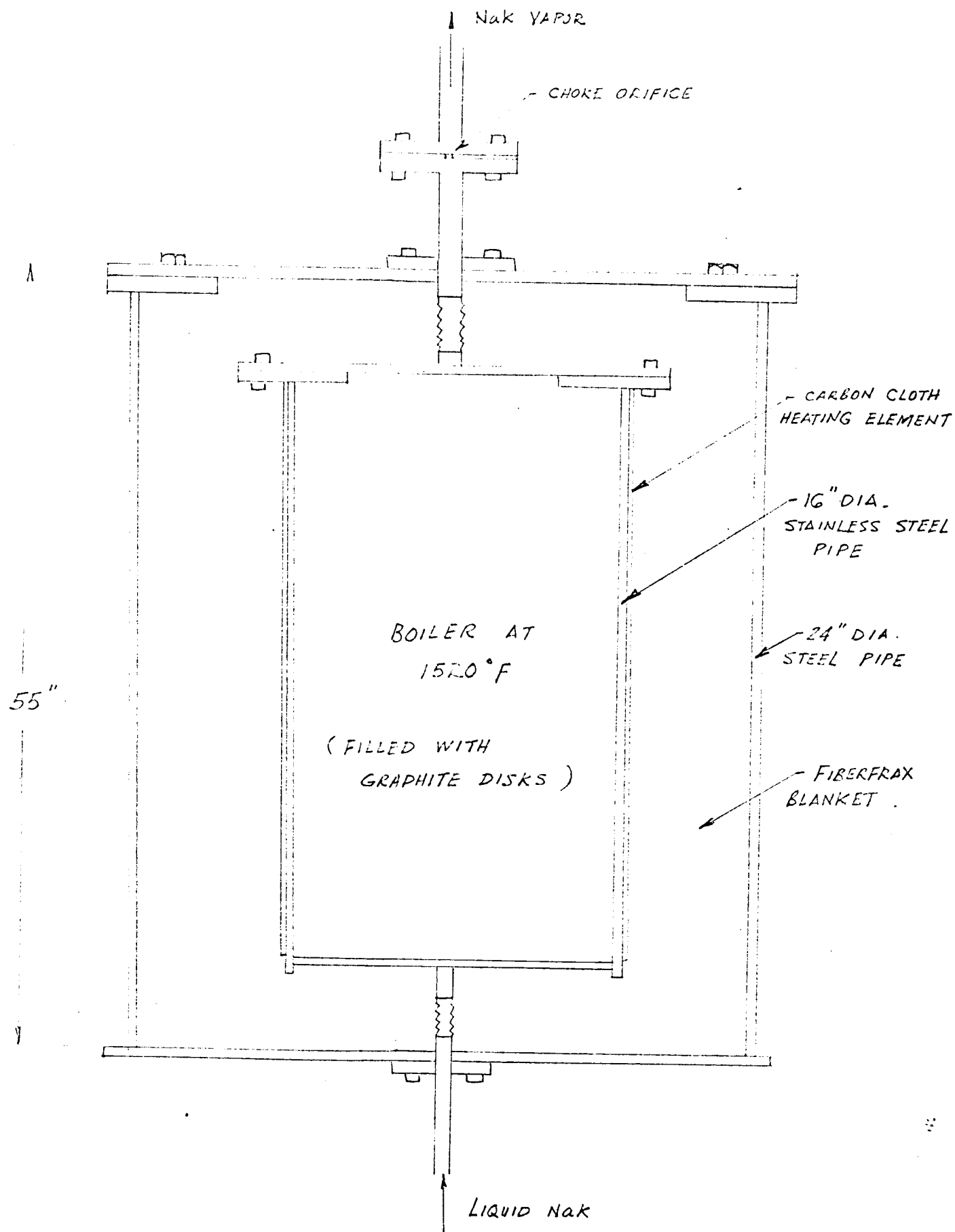


FIG. 3.1. SKETCH DRAWING OF NaK BOILER

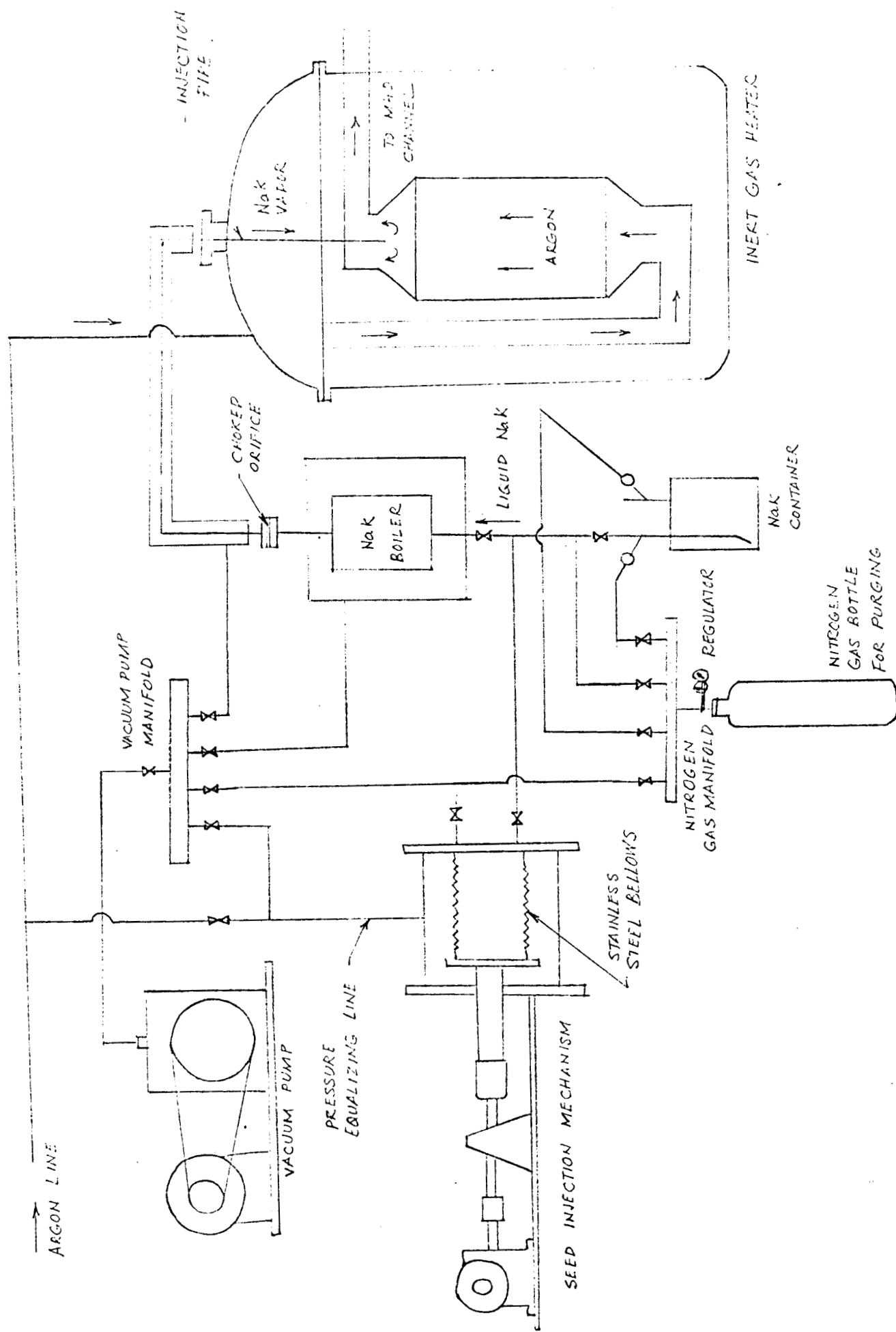


FIG.3.2 SEED INJECTION SYSTEM

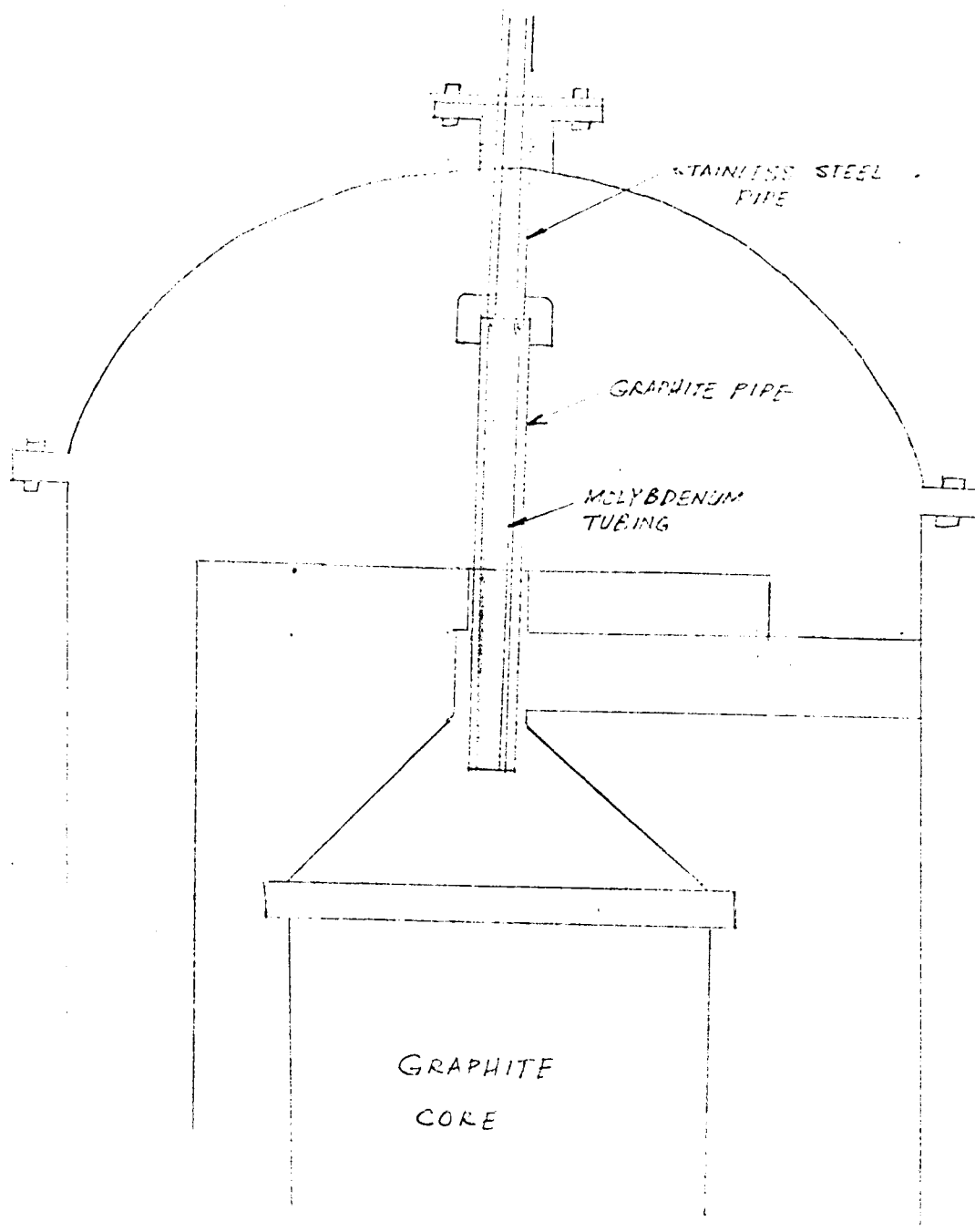


FIG. 3.3

SKETCH DRAWING SHOWING
INJECTION PIPE

FIG. 4.1 CHANNEL CROSS-SECTION (full scale)

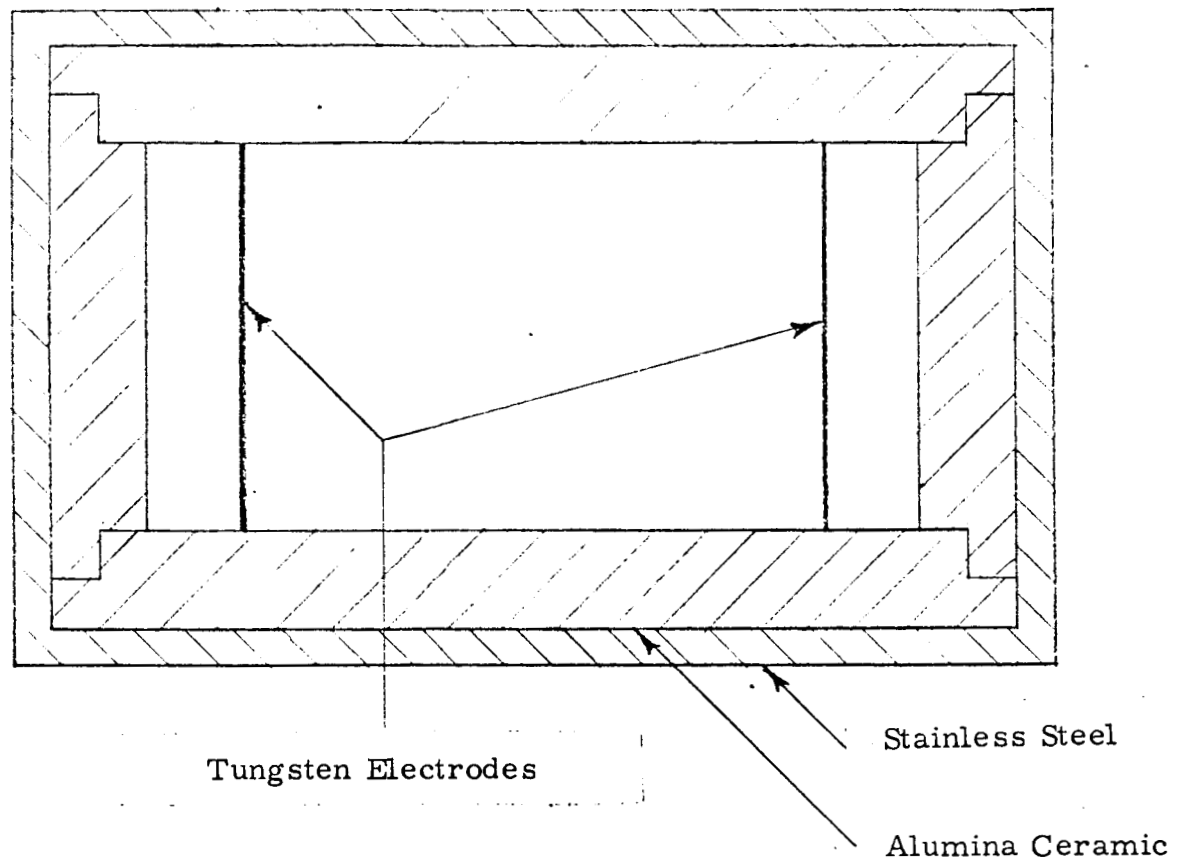
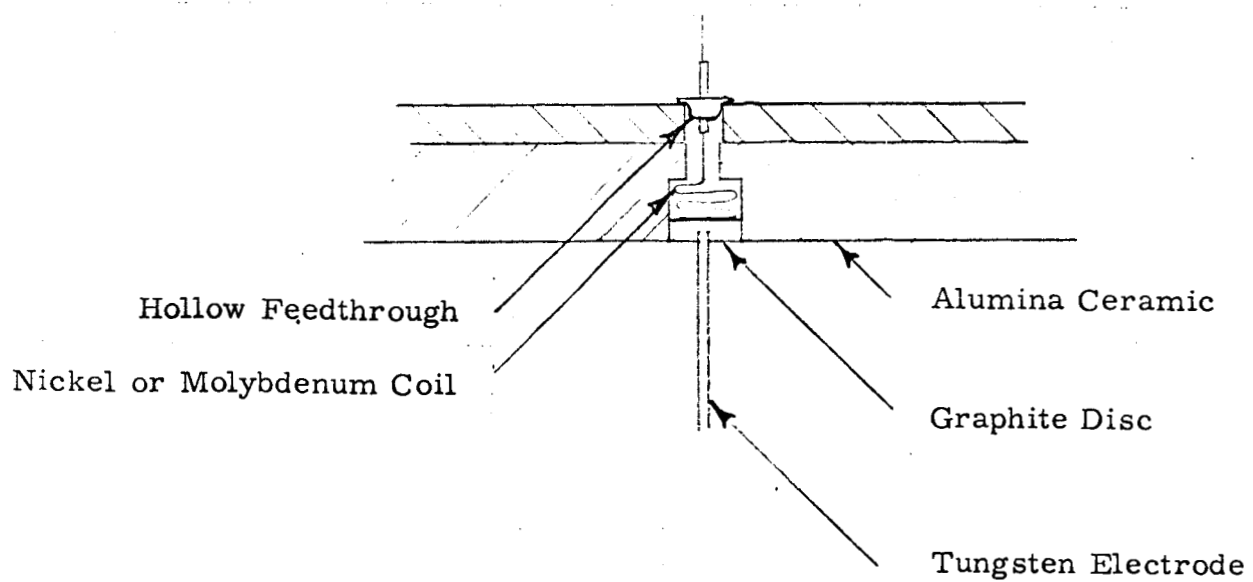
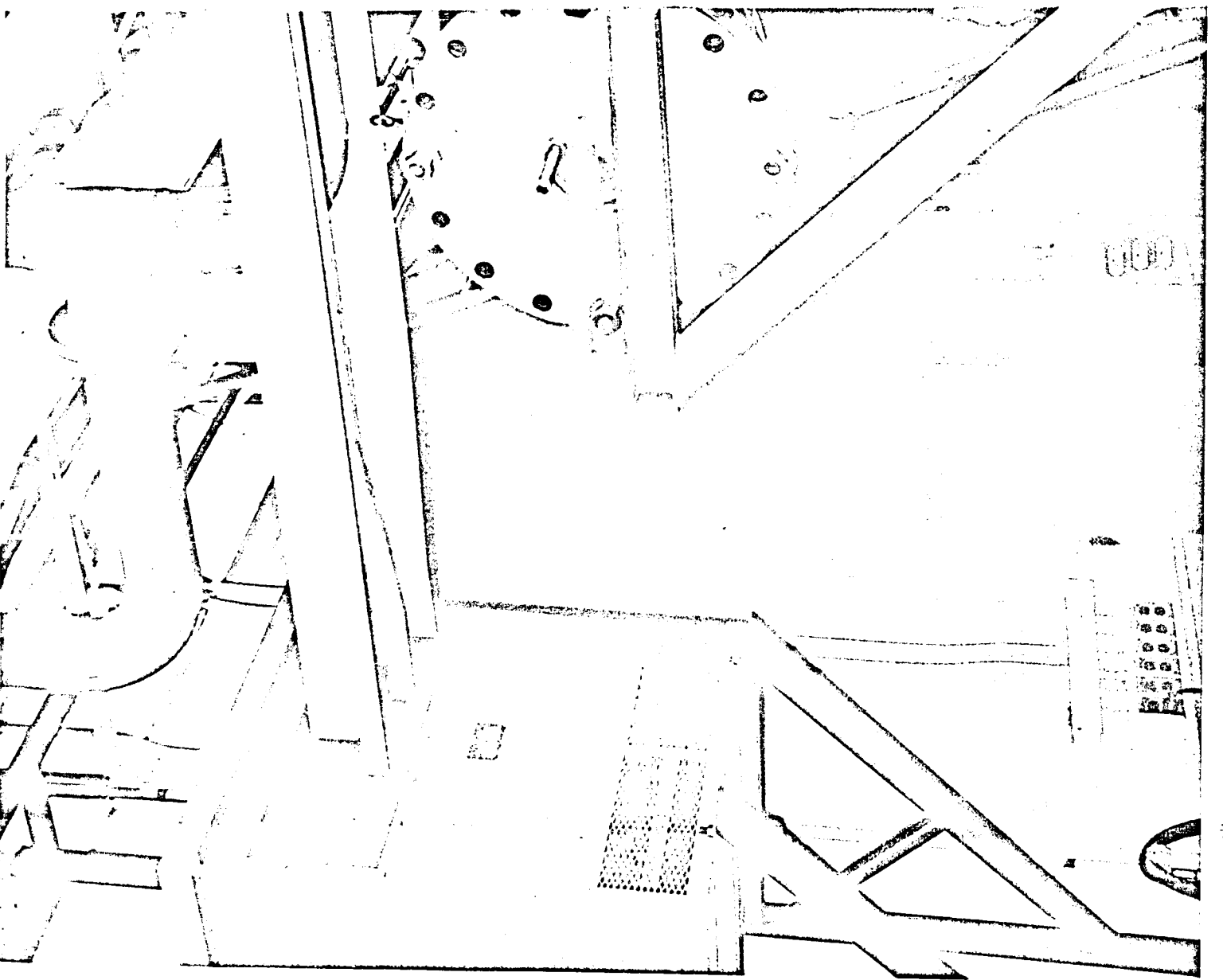
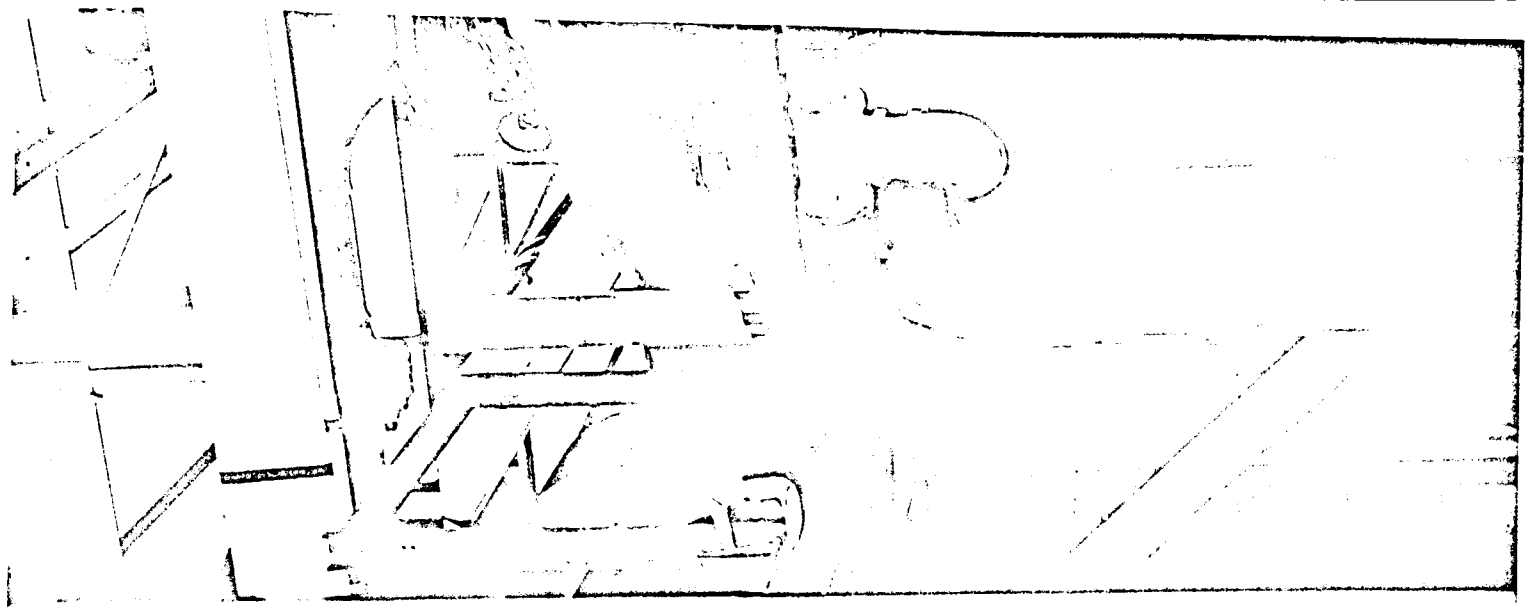
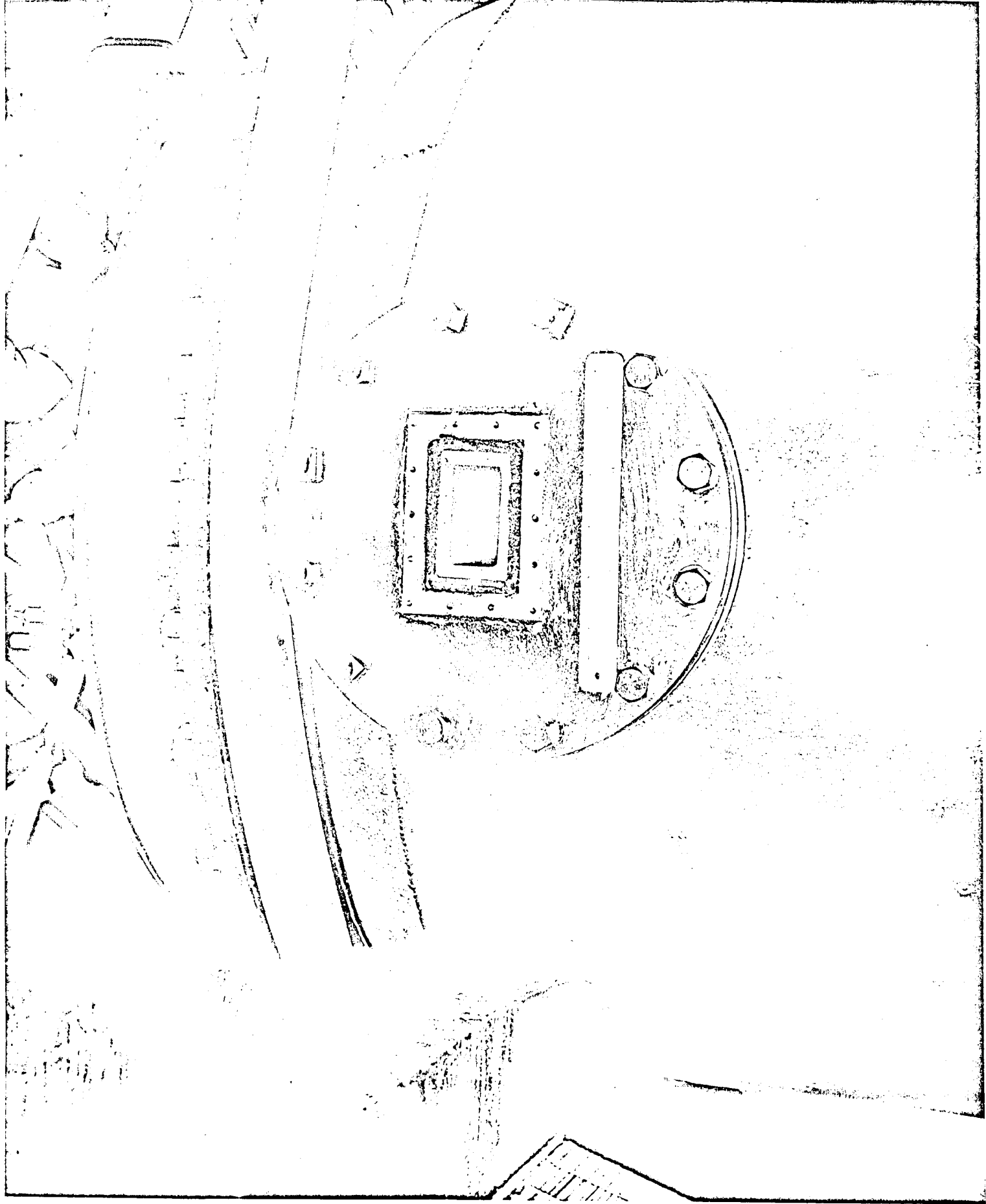


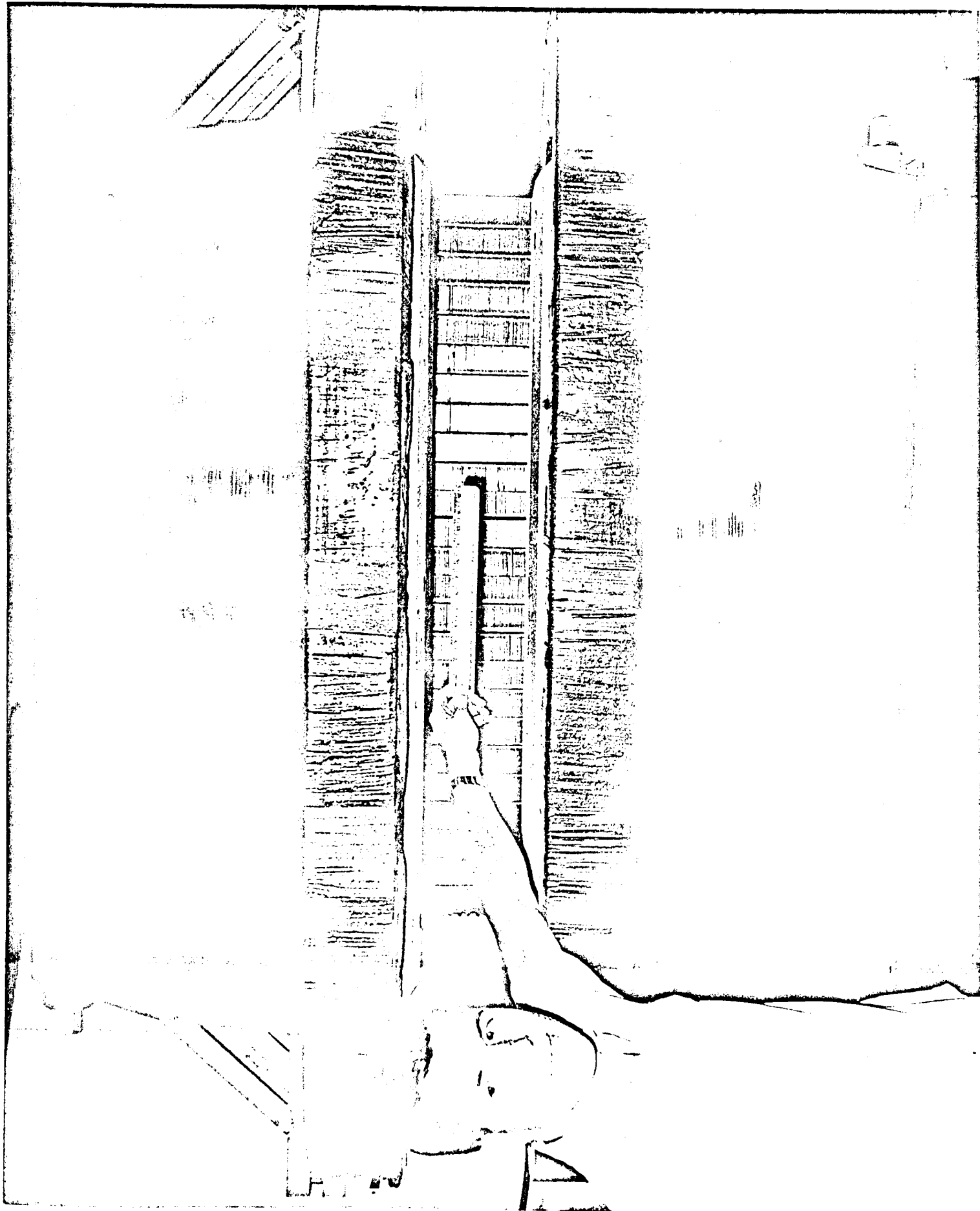
FIG. 4.2 ELECTRODE INSTALLATION DETAIL (full scale)

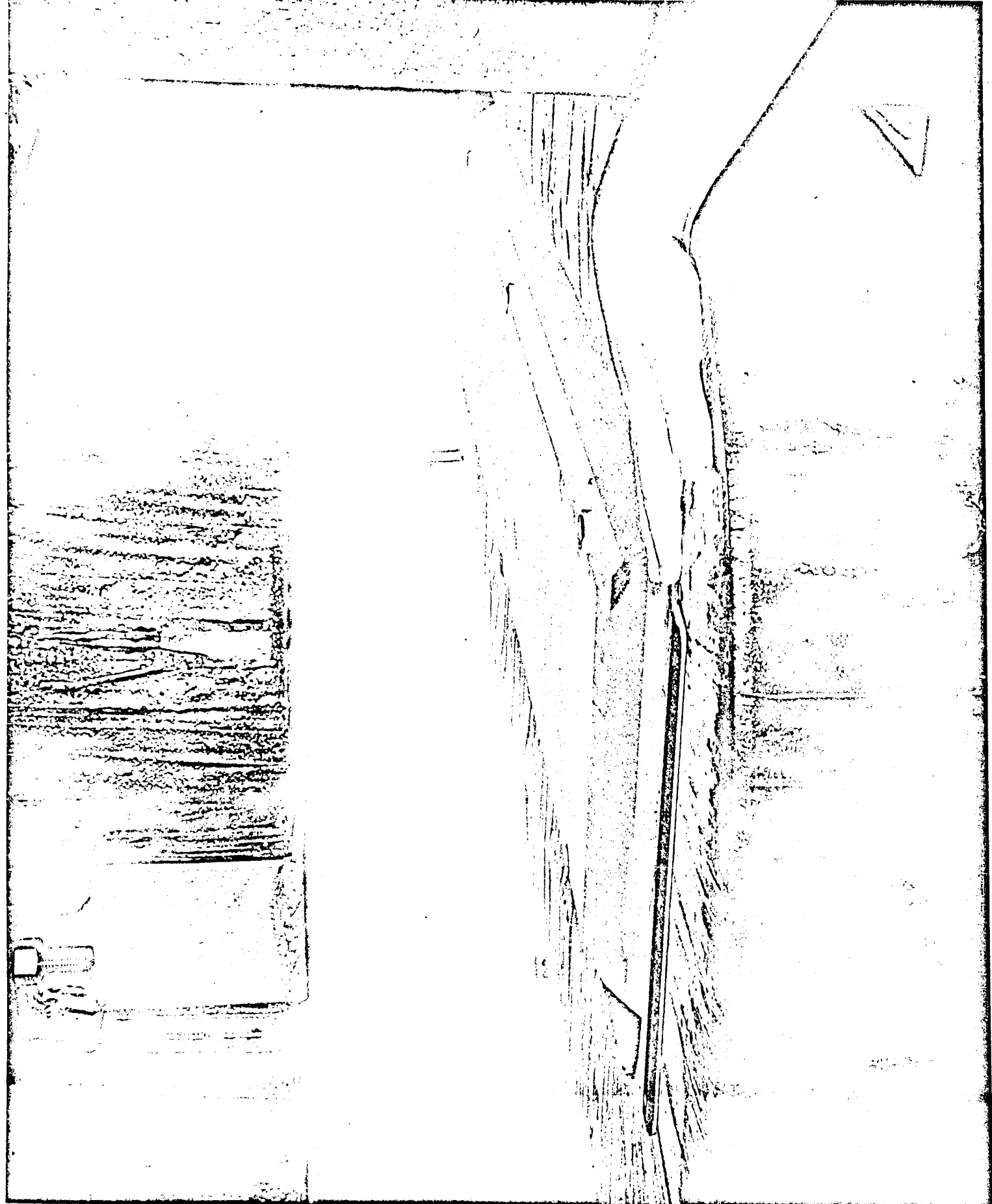




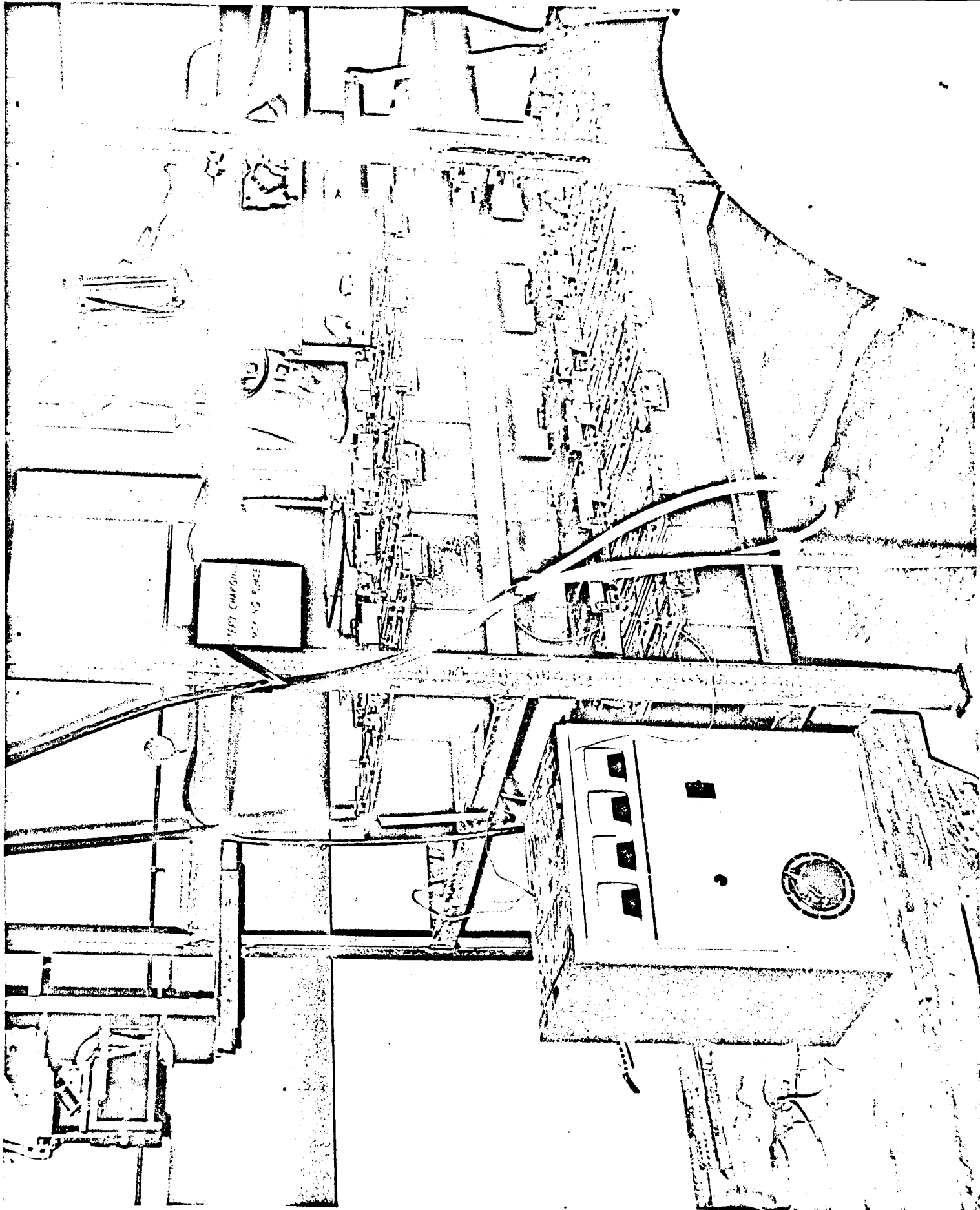












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